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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report No. 32-954

Mariner IV Mechanical Operations

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ABSTRACT

This report summarizes the salient features of spacecraft mechanical operations based on experience with the *Mariner IV* spacecraft. The scope of these operations is presented through photographs of various flight and test configurations. Particular operational aspects, including assembly problems, flight preparation, personnel, and documentation, are discussed. General conclusions are drawn regarding spacecraft mechanical operations that may be of value to future space projects.

AUTHOR

I. INTRODUCTION

The *Mariner* Mars 1964 mission was a flyby of the planet Mars by a spacecraft launched during the 1964 opportunity. The primary objective of the mission was to conduct scientific observations of the planet and to transmit the results of these observations to Earth. A secondary objective was to provide experience and knowledge about the performance of the basic engineering equipment of an attitude-stabilized flyby spacecraft during a long duration space flight farther away from the Sun than the Earth. An additional secondary objective was to conduct certain field and/or particle measurements in interplanetary space and in the vicinity of Mars. These measurements included televising the planet's surface and obtaining atmospheric data based on occultation of the spacecraft's radio signals by the planet.

The new spacecraft design was designated *Mariner C* class, based on *Ranger/Mariner* technology. It used innovational developments only where absolutely necessary, or where equipment lifetime was not a primary concern. *Mariner III* and *Mariner IV* are spacecraft of this class. *Mariner III* was launched on November 5, 1964, but was unable to function as designed because of a structural failure of the launch vehicle's aerodynamic shroud which enclosed the spacecraft. Because of the failure, the shroud could not be jettisoned and the spacecraft died approximately nine hours after launch when its battery was depleted. A new protective shroud was designed and fabricated for *Mariner IV*, which was launched on November 28, 1964. All systems functioned as designed and *Mariner IV* proceeded to complete all mission objectives. It continued to function nominally until the mission was temporarily terminated on October 1, 1965. At that time, the spacecraft was commanded to transmit over the low-gain antenna so that telemetry could be received by Earth at a later date. Since then, the spacecraft has again come within range of telemetry reception by Earth.

This report outlines the scope of mechanical operations performed on *Mariner* Mars 1964 flight spacecraft and discusses those aspects of spacecraft mechanical operations that may be generally applicable to other projects. Rather than present a detailed description of how the mechanical operations were performed on the *Mariner* project, the scope of these operations will be suggested by a list of the major spacecraft tests with accompanying photographs of how the tests were mechanically implemented. The responsibilities of the mechanical test team will be discussed, and some general conclusions drawn regarding both the staffing of mechanical teams and the mechanical preparation of a spacecraft for flight.

II. SCOPE OF MECHANICAL OPERATIONS

Spacecraft mechanical operations are an integral but separable part of spacecraft system operations. The functions of system operations are (1) to qualify the spacecraft for flight by a series of operational and environmental tests and (2) to prepare the spacecraft for flight. On the *Mariner* Mars 1964 project, the qualification function was performed at JPL in Pasadena and the process of flight preparation was performed at the Air Force Eastern Test Range (AFETR). Mechanically, however, the qualification and flight preparation processes are similar and, in some cases, duplications of one another. Therefore, they are discussed here as a single process, although certain portions of each occur more than once.

A. Test Configurations

The qualification of a spacecraft for flight is accomplished through a thorough and rigorous test program which requires a wide variety of spacecraft mechanical configurations. Figures 1 through 10 illustrate the major tests and the mechanical configuration for each test, as well as the inflight boost and cruise configurations.

It may be interesting to note that only the vibration test, matchmate test (mating with the second stage of the launch vehicle), free-mode test, and weight and center-of-mass determination require that the spacecraft mechanically resemble the two flight configurations.[1] These tests, as well as the launch from the AFETR, require that the spacecraft assume a configuration for transportation or shipping, as shown in Fig. 10.

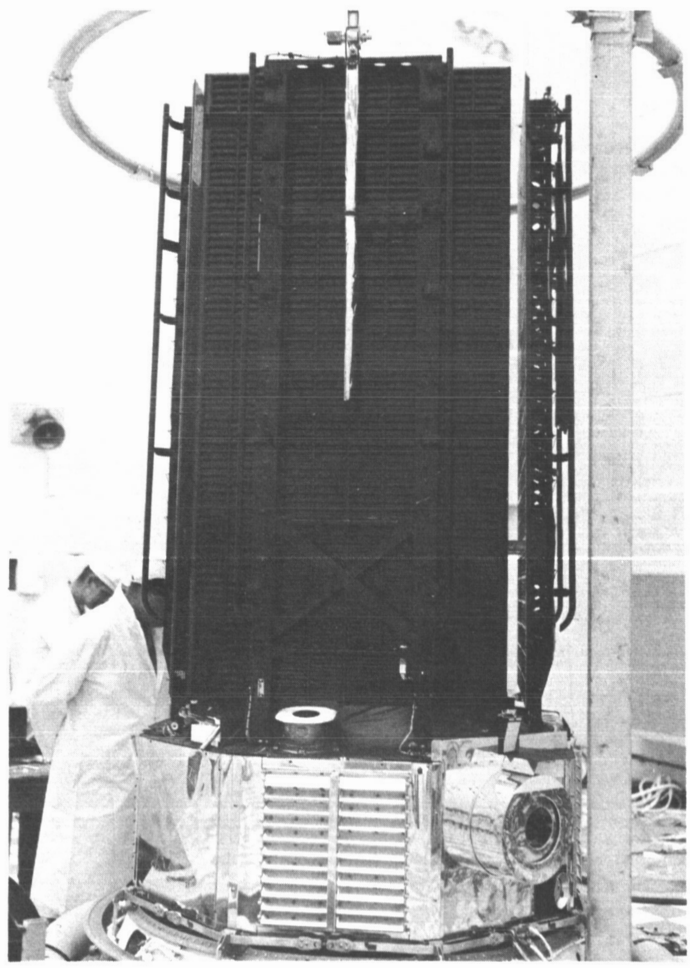

Fig. 1. Flight spacecraft boost configuration

[1]For a description of the factors that influence mechanical design of the spacecraft, see Spehalski, R. J., *Mariner Mars 1964 Spacecraft Mechanical Configuration,* Technical Report 32-933, Jet Propulsion Laboratory, Pasadena, California, Sept. 1, 1966.

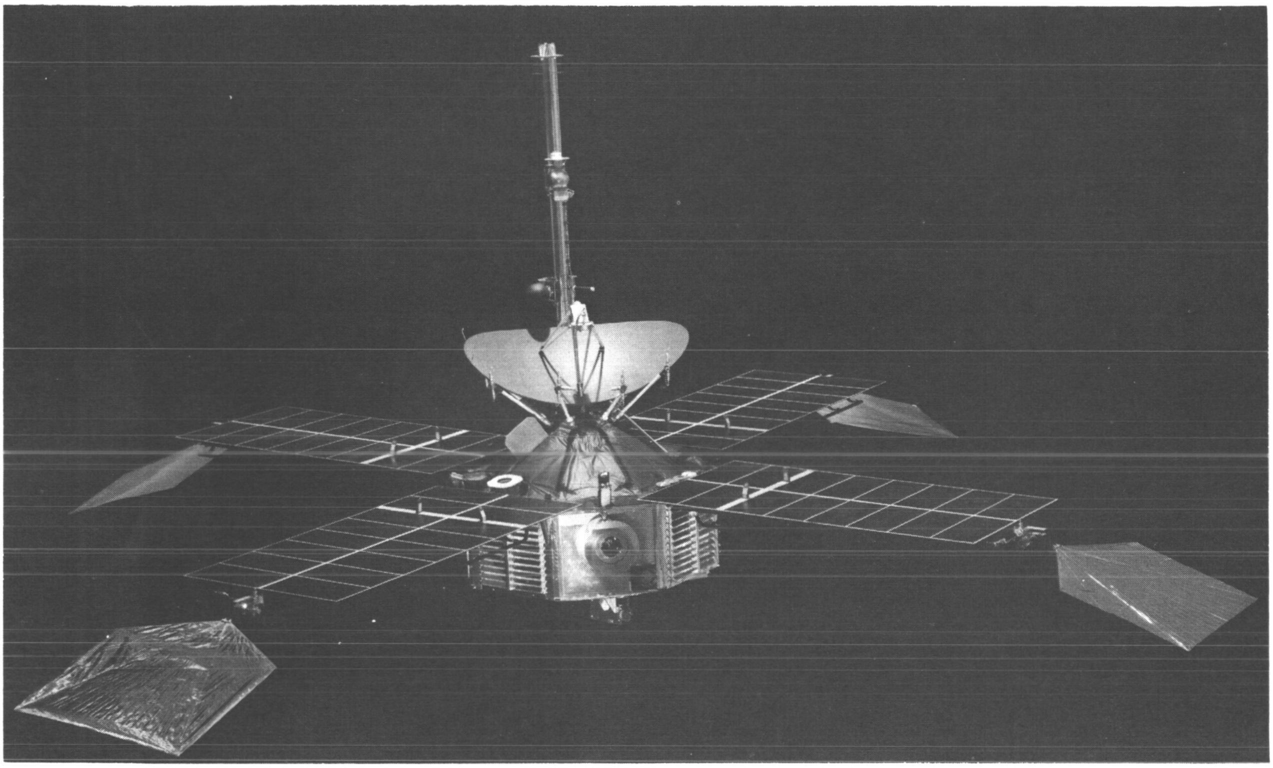

Fig. 2. Flight spacecraft cruise configuration

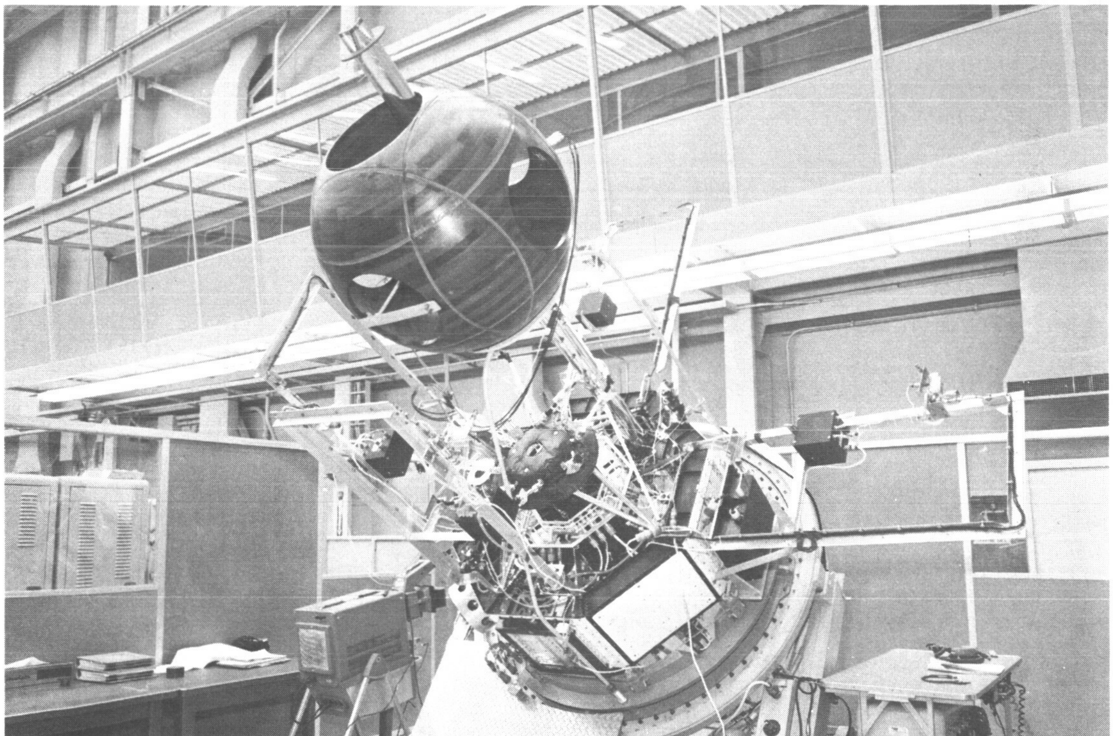

Fig. 3. System test

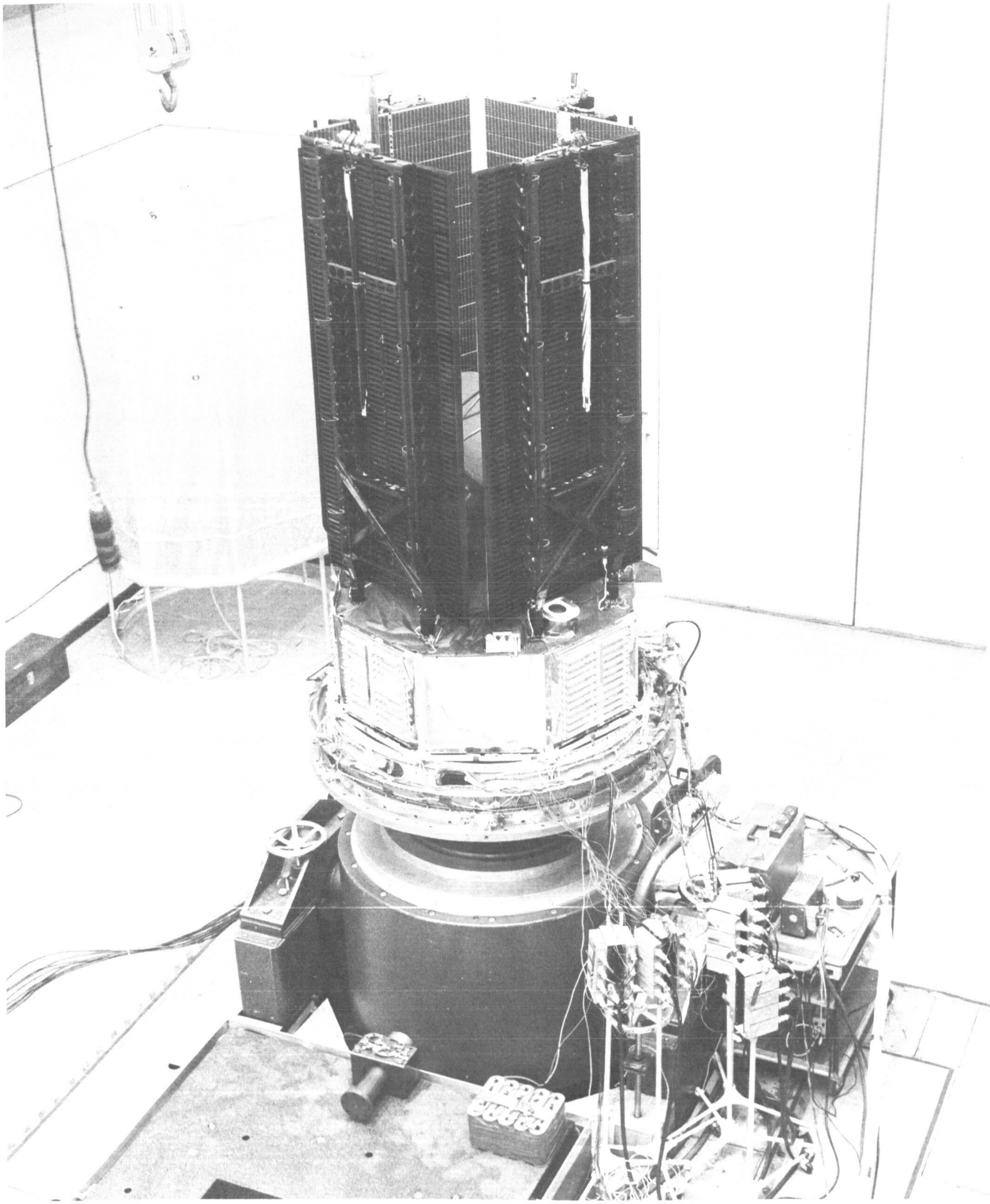

Fig. 4. Vibration test

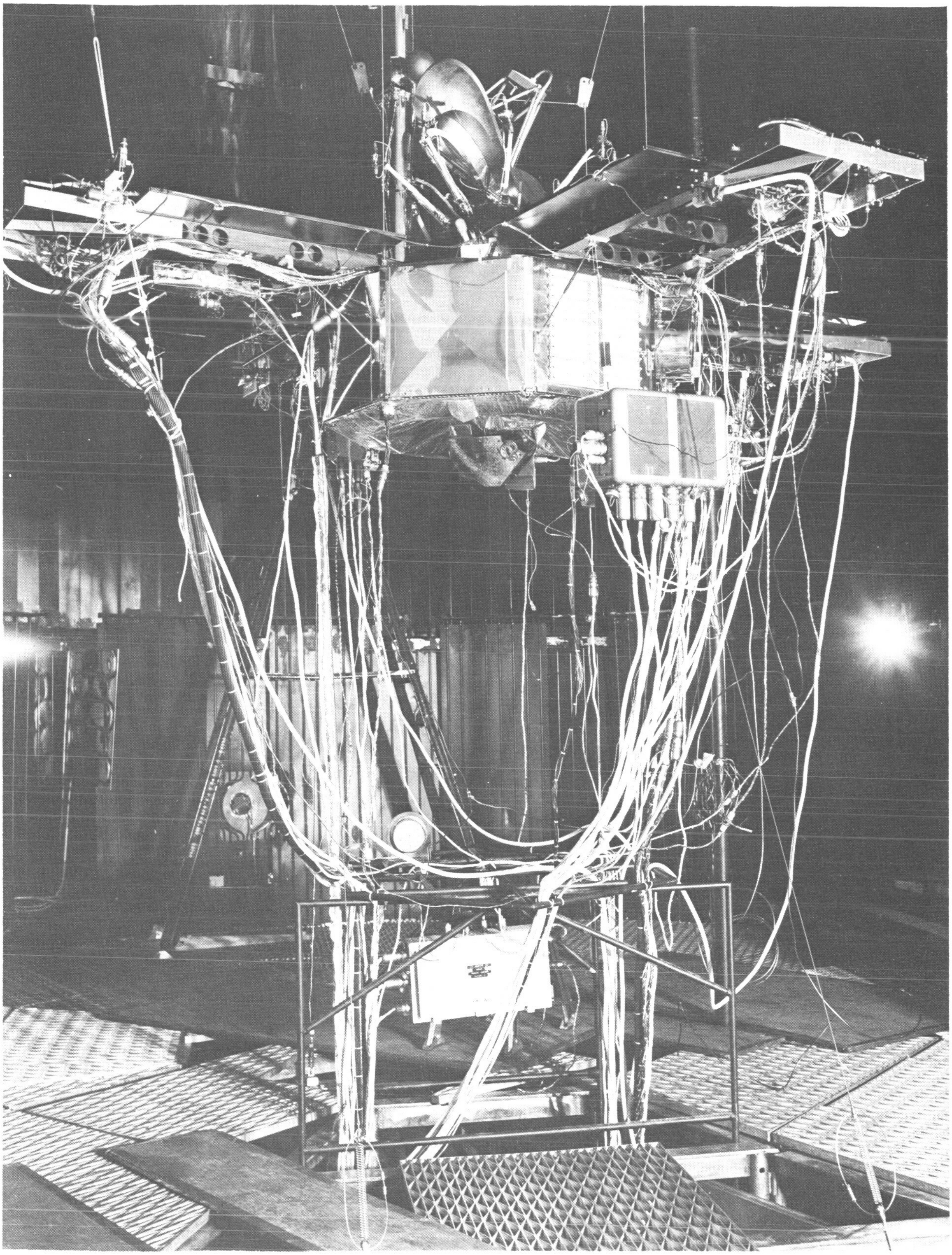

Fig. 5. Thermal vacuum test

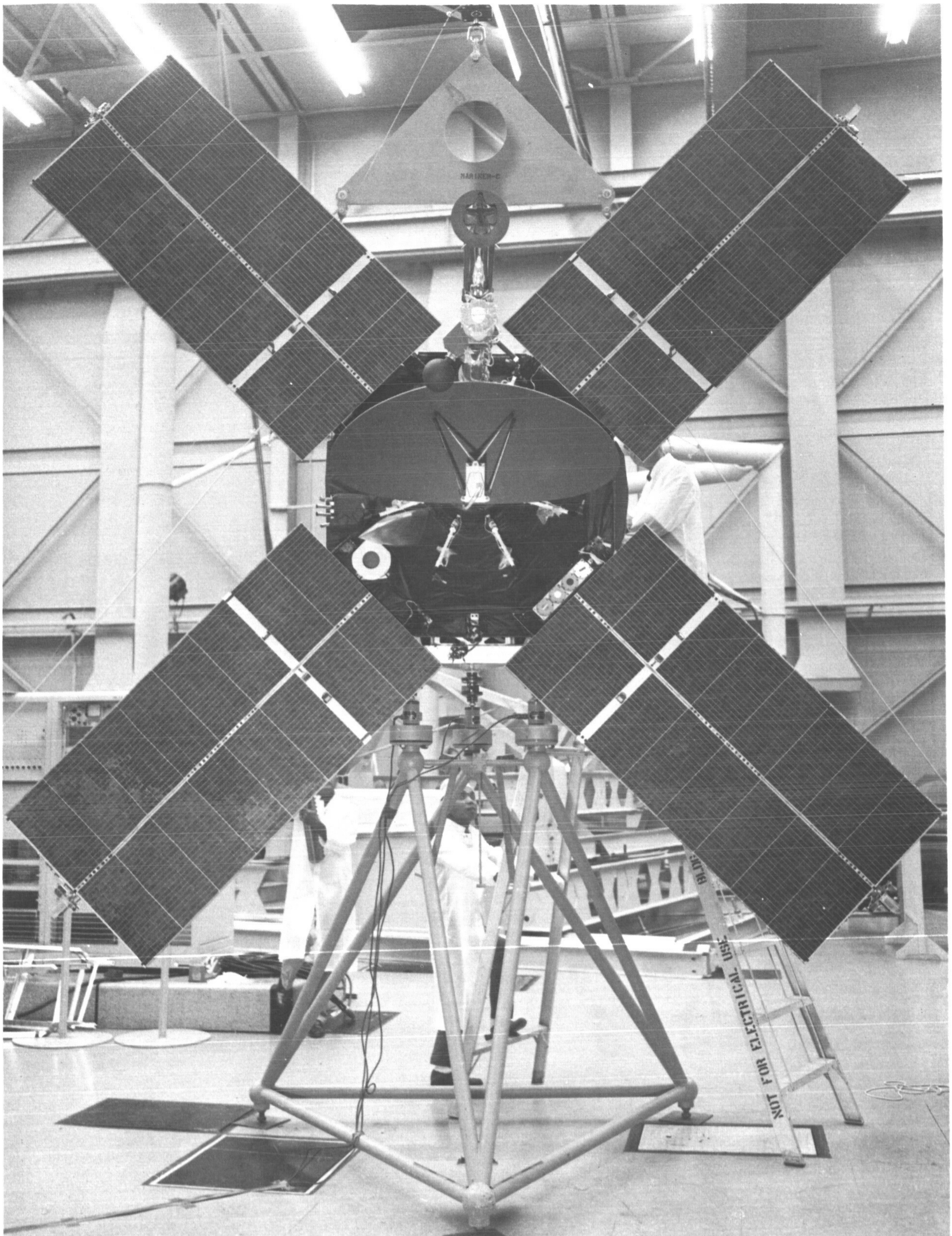

Fig. 6. Weight and center-of-mass determination

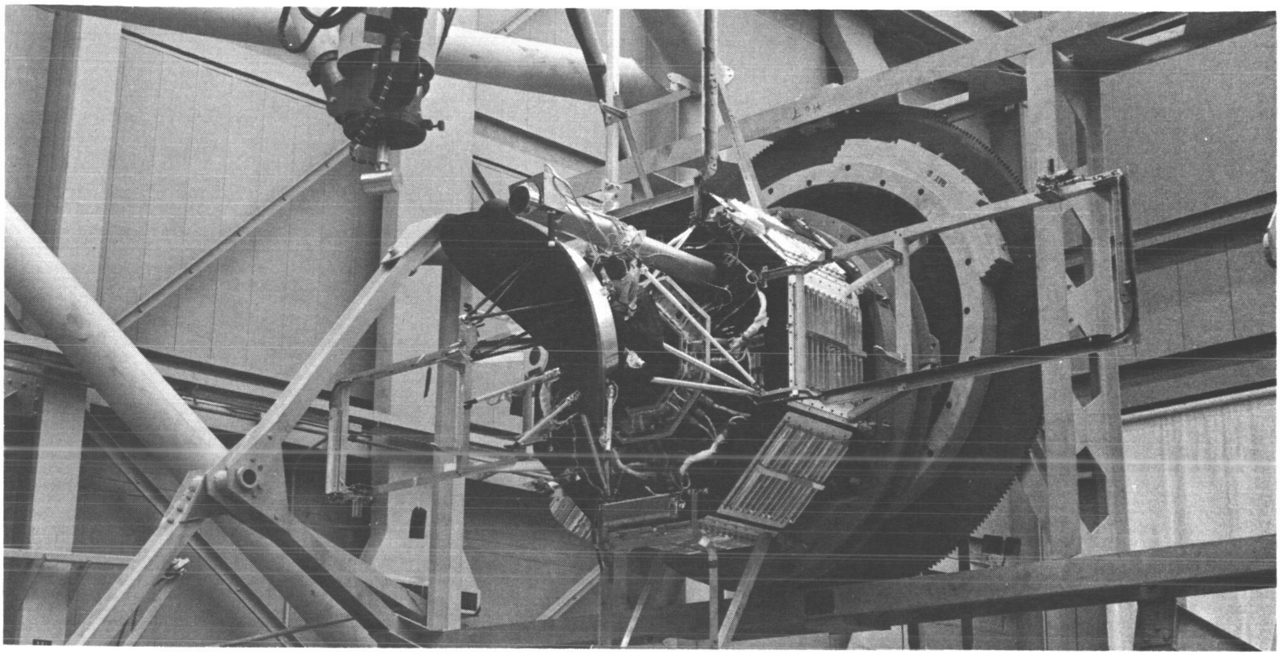

Fig. 7. Magnetometer mapping

Fig. 8. Free mode test

Fig. 9. Spacecraft/*Agena* adapter and shroud matchmate

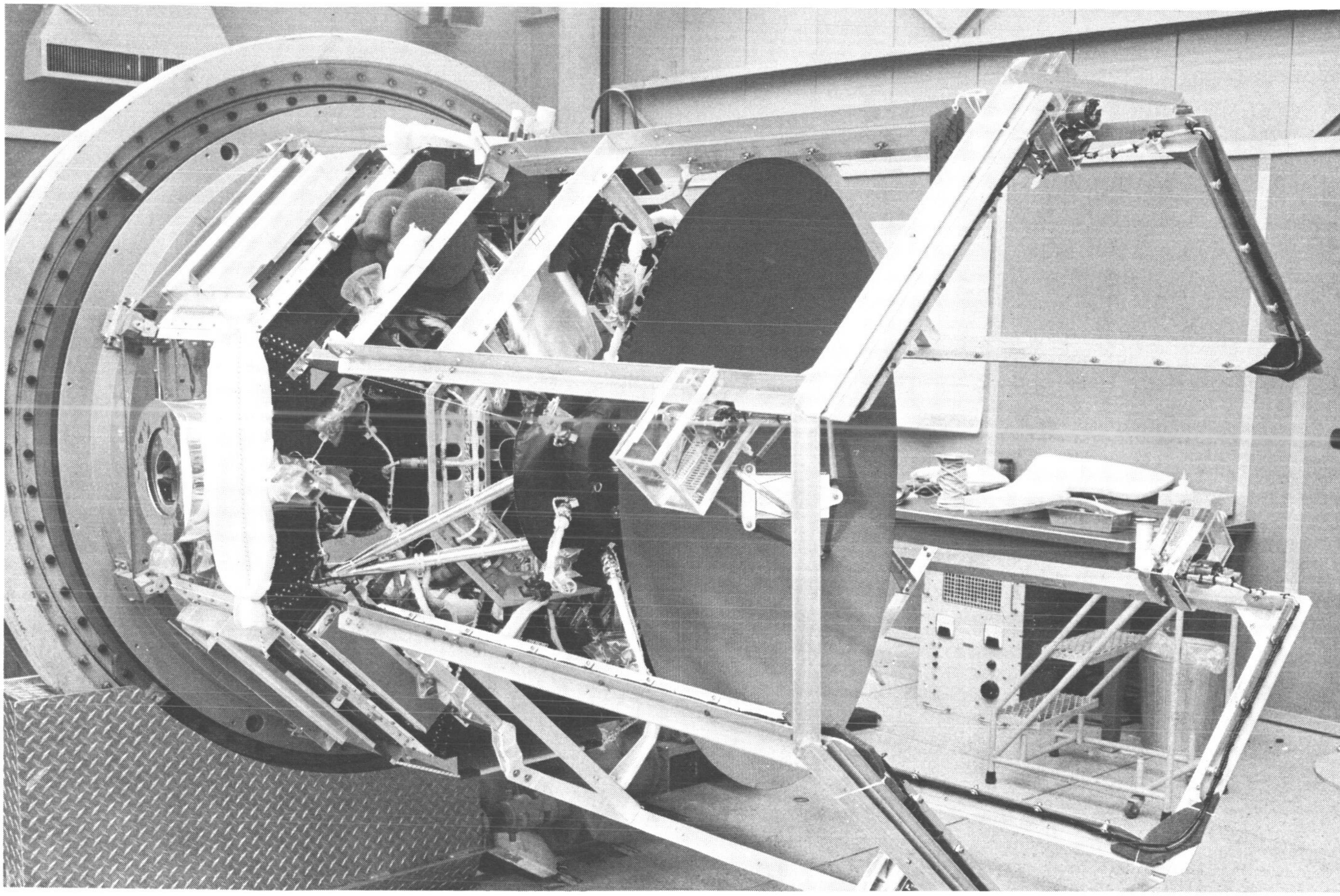

Fig. 10. Flight spacecraft prepared for shipping

The illustrations indicate that many mechanical operations are performed on a flight spacecraft from the time individual pieces of equipment are delivered to the Spacecraft Assembly Facility (SAF) until the vehicle is launched. The responsibility for the performance of these operations is assigned to a mechanical test and operations team. The team's primary functions are (1) to mechanically prepare the spacecraft for qualification tests within the specified schedule and (2) to ensure that the spacecraft, as launched, is mechanically equivalent to what it was when qualified.

In carrying out this responsibility, the test team is subject to schedule pressure. The *Mariner IV* spacecraft, which may be considered typical of unmanned, interplanetary systems, was permitted approximately seven months from initial flight equipment deliveries until it was to be ready for launch. Of this time, five months were allowed for JPL Pasadena operations to qualify the spacecraft for flight, and two months for the AFETR operations. The *Mariner IV* original test and operations schedule allowed 30 to 40% of this total time for mechanical operations. This amount of time would appear to be adequate. However, since some equipment can be delivered late, initial assembly can be inefficient on a time basis and can occur only as the equipment becomes available. Also, as testing proceeds and problems are discovered, electronic troubleshooting teams use time normally allotted for the mechanical operations. Although margins are placed in the test schedule for troubleshooting, this time is not always adequate, particularly when troubleshooting requires extensive mechanical operations—such as during thermal-vacuum testing, when a complicated test setup (Fig. 5) must be disassembled to permit spacecraft mechanical operations and electrical troubleshooting. Since the time for mechanical operations and the launch schedule remain constant, many mechanical operations must be performed at odd hours and often on a multiple shift basis. This is a fatiguing mode of operation that increases human susceptibility to error. As the schedule proceeds, the allowable margin for mechanical error decreases. These demanding conditions impose special requirements on the organization and staffing of the mechanical test team.

B. Mechanical Test and Operations Team

On the *Mariner* Mars 1964 project, the mechanical test and operations team for each flight spacecraft consisted of the following permanent members:

1. A systems mechanical engineer (a mechanical engineer from the JPL Project Engineering Division)
2. A spacecraft cognizant mechanical engineer (a mechanical engineer from the JPL Engineering Mechanics Division)
3. A lead mechanical technician
4. A mechanical inspector

Additional technical support was provided, as required, from a pool of *Mariner* spacecraft mechanical technicians. Most mechanical operations needed two or three personnel from this pool; each technician worked under the direction of the lead mechanic.

The functional organization for individual spacecraft mechanical test and operations teams is shown in Fig. 11.

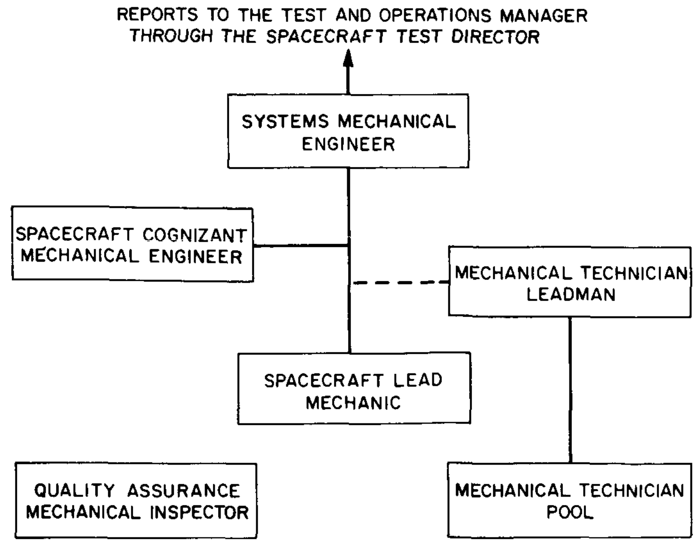

Fig. 11. Spacecraft mechanical test and operations team

The two cognizant mechanical engineers shared responsibilities so operations could be performed when either engineer was present. The systems mechanical engineer was responsible for interface operations with test facilities and the launch vehicle, as well as for the overall spacecraft. The spacecraft cognizant mechanical engineer, possessing a greater familiarity with the mechanical design and details of the spacecraft, directed assembly operations during initial buildup. This arrangement worked very well, since each engineer learned the other's duties, and either one could accept total responsibility. This arrangement was particularly effective when multiple shift operations were required.

The mechanical technician leadman, a senior technician with broad experience in aerospace mechanical technology, was responsible for the overall performance and administrative supervision of the mechanics of all the spacecraft. It was his duty to assign individual technicians to support operations on any of the two flight and one spare spacecraft, and to direct mechanical work in support of functions related to the spacecraft.

The spacecraft lead mechanic, a senior technician possessing technical supervisory qualities as well as mechanical skills, was responsible for the detailed direction of assigned mechanics from the technician pool. He was a permanent member of a particular spacecraft team, and was under the technical direction of the mechanical engineers responsible for the spacecraft.

A pool of skilled mechanical technicians was used to handle the varying workload of a prototype and three flight spacecraft. Assignments were made and shifted in accordance with each spacecraft's operations schedule. This approach served two purposes: (1) efficient use of personnel by minimizing deadtime, and (2) maintenance of technician proficiency by providing nearly continuous experience in all spacecraft assembly tasks.

III. DISCUSSION OF OPERATIONS

Spacecraft mechanical assembly is by definition an interface operation. Therefore, two types of mechanical problems can be expected (1) inadequacy of installation hardware, and (2) mismatch of mating parts. In a tightly scheduled project, these interface problems are more likely to occur because of inadequate investigation of seemingly minor design details.

A. Assembly

In the assembly of the *Mariner* flight spacecraft, many problems arose with installation hardware (mechanical fasteners, cable clamps, washers, etc.). Specified screws were too long, too short, or unavailable. Screws with locking devices and other hardware were not designated when they should have been, or were unavailable when they were specified. Many of these problems were discovered on the proof test model (PTM), but due to the tight schedule, they were not corrected in time for operations on the flight spacecraft. These types of problems retard spacecraft assembly operations, since each one requires several actions to solve it:

1. The problem must be properly identified

2. An acceptable solution must be found and approved so that operations may proceed

3. The documentation must be corrected and approved

4. New hardware may have to be ordered to cover the requirements

5. A procedure must be established for ensuring that the proper hardware is installed when it becomes available

Mariner operations were expedited by giving one man the sole responsibility of making sure that these tasks were accomplished.

Solution of installation hardware problems on the *Mariner* project was expedited through the use of a flexible engineering change order system. This system enables the spacecraft cognizant engineer to initiate drawing changes whenever installation problems are encountered. Rapid approval and release of these changes provide current documentation in the assembly areas upon which assembly personnel can rely.

The other problem that occurred during initial mechanical assembly—mismatch of mating parts—is common to any type of assembly operation. It is probably a truism that most things do not fit right the first time. Mechanical fitting problems may occur for any number of reasons, but they require similar actions to solve them as do those problems of installation hardware. Since mechanical fitting problems can occur with any subsystem, it is difficult for one man to be assigned to resolve them. On the *Mariner* Mars 1964 project, mechanical fitting problems were handled through the identification of each problem by the cognizant spacecraft mechanical engineer and resolution of it through the subsystem cognizant engineer. Since these interface problems were the most pressing ones, additional follow-up was usually required by cognizant spacecraft engineers to ensure that they were solved within the time schedule.

B. Flight Preparation

The major mechanical problem associated with preflight operations was assurance that the spacecraft had been properly assembled. All items must be correctly installed and secured and all nonflight items removed. On *Mariner* Mars 1964 the latter was guaranteed through the use of a tote board. This board held a pocket for every nonflight item that was attached to the spacecraft (protective devices, dummy pinpullers, safe/arm pins, etc.). Every pocket on the board had to contain the proper device before the spacecraft was permitted to be encapsulated for flight.

Assurance that the spacecraft is properly assembled is more difficult to achieve. In contrast with electrical connections, end-to-end checks cannot be made. Reliance must be placed on the integrity and thoroughness of the technical personnel and on the signed-off procedures and inspection reports. This final assembly checkout is probably the single most disquieting facet of preflight mechanical operations. There is no single device that testifies, unequivocally, to the fact that the spacecraft has been properly prepared for flight.

C. People and Procedures

Ultimately, people and not procedures must be relied on for confidence in the flight worthiness of a spacecraft. *Mariner* experience indicates that it is extremely difficult to evolve good mechanical assembly procedures during a spacecraft development program. The establishment of useful procedures depends on inputs from the people actually doing the work. On a tight schedule, the procedure exists, but is dynamic. Corrections are necessary but exist only in the minds of the engineers and technicians and are committed to paper only when time is available. Sometimes corrected revisions are issued long after the time they are needed. When a corrected procedure becomes available it may be difficult to persuade assembly personnel to use it. They have probably done the same operation many times without it and feel they can continue doing the job correctly without a procedure. Also, if procedures contain errors or inaccuracies, and a method does not exist for making rapid corrections, the procedures will be ignored. Therefore, for a system to effectively use formal procedures, a quick-change technique is required that is similar to that mentioned above for engineering drawings. Similarly, the responsibility for maintaining current procedures should be assigned to a specific individual.

The nature of spacecraft mechanical operations complicates the use of procedures. Since spacecraft assume many different configurations (Fig. 1 through 10) the proper procedure for performing a given operation in one configuration may not be correct in another. Therefore, it is difficult to generate procedures that are explicit and accurate, yet general enough to cover all configurations. For *Mariner* Mars 1964, the general procedure method was used, and the applicable parts extracted to cover particular operations.

Because of the strong reliance on people for the proper performance of spacecraft mechanical operations, their careful selection is very important.

The cognizant mechanical engineers set the tone of the working environment. Along with technical competence, they must possess a thorough understanding of the mechanical aspects of the spacecraft, be precise in their execution of mechanical operations, be aware of possible problem areas, and be persistent in pursuing problems to a satisfactory solution. Conversely, participation in spacecraft mechanical system operations provides excellent training for engineers responsible for spacecraft mechanical design. Knowledge gained through this experience permits feedback to the design of future spacecraft so that mechanical operations can be more simply and therefore more reliably performed.

In addition to possessing suitable mechanical skills, the prime requisite of mechanical technicians is that they always exercise care. After a technician has performed the spacecraft assembly operations several times, he has learned most of what he needs to know to repeat these operations. From here on, the principal challenges to his ability are for speed, thoroughness and care. Spacecraft, by nature, are fragile, and carelessness, particularly late in the schedule, can be catastrophic. Finally, the technicians should be compatible with all team members. Preparation of a spacecraft for flight requires close teamwork for several months. Incompatibility can cause dissension that can be detrimental to performance.

IV. CONCLUSIONS

The ultimate success of the *Mariner IV* flight suggests that all aspects of the program were properly performed including the mechanical operations. This program provided extensive experience that should be useful to future space projects. These conclusions and recommendations, in particular, should be valuable to all spacecraft mechanical teams.

A. Personnel Competence and Experience

The primary requirement of the mechanical team is to perform all its operations correctly and within schedule. The conflicting aspects of this requirement generate pressures that can create problems. This fact and the increasingly dire consequences of mechanical accidents late in the schedule emphasize the need for careful personnel selection for mechanical teams. (1) It is important that a permanent member of the team with technical supervision responsibilities (a spacecraft cognizant mechanical engineer) have an intimate knowledge of the spacecraft's mechanical details. Also, this "cradle-to-grave" philosophy provides for the continual upgrading in spacecraft mechanical design such that mechanical operations on future spacecraft are simple and safe.

(2) Similarly, technician crews should be staffed by personnel exerienced on spacecraft mock-ups, test models, etc. and who, therefore, are thoroughly familiar with the spacecraft before working on flight units. (3) Efficient personnel utilization and maintenance of technical proficiency can be achieved through the use of a spacecraft technician pool. However, the suitability of this approach may be more strongly influenced by other factors, such as organization structure, personalities, schedules, etc.

B. Response to Project Directives

The mechanical team must be prepared to respond quickly to project directives that require changes in operation sequence and schedule. In a tightly paced program, the project manager must maintain flexibility in altering test sequences and schedules to satisfy the overall mission objectives. The mechanical team must recognize and handle these changes as they occur, as well as inform the project manager of the effects of these operations on the mechanical integrity of the spacecraft. For example, just as the *Mariner IV* spacecraft was being prepared for transportation to the environmental laboratory for vibration testing, it was decided that an electronic assembly should be replaced. This operation required extensive disassembly of the spacecraft. The mechanical team, after working long hours in the tedious operation of buttoning-up the spacecraft, had to repeat the operation on an accelerated basis in order to maintain the schedule.

C. Documentation

A formal change method should be devised and personnel assigned for its execution, to ensure the rapid and thorough initiation and follow-up of changes to assembly and installation drawings and procedures.

D. Preflight Mechanical Verification

There is no single test that verifies that the spacecraft is mechanically ready for flight. For this verification, reliance must be placed upon proper monitoring and control by the cognizant mechanical engineers, proper use of mechanical procedures by operating technicians, and monitoring and sign-off of documentation by quality assurance personnel.

E. Continuity of Effort

The reliance upon personnel for the thorough and successful performance of spacecraft mechanical operations accents the need for continuity of effort during spacecraft system operations. The mechanical team concept, with cognizant mechanical engineers and a lead mechanic permanently assigned to each spacecraft, provides this continuity in mechanical operations. This approach provides each permanent team member with a sound, current appraisal of the spacecraft status as well as particular spacecraft peculiarities.

This report has been a generalized discussion of the salient aspects of spacecraft mechanical operations. The intent here has been to warn the reader of those features of spacecraft mechanical operations that are most important to their successful completion. Discussion of detailed implementation has been avoided not for lack of importance, but because these details are not generally applicable, being a function of the spacecraft mechanical design.

In spacecraft mechanical operations, as in all aspects of a space program, the detailed implementation of an overall philosophy is of major importance. Recognition of the general aspects presented here, followed by the thorough and competent detailed mechanization of the operations plan, are essential to the successful completion of spacecraft mechanical operations.